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By H. C. SHELLARD

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The really cold weather began just before Christmas with an invasion of easterly winds from central Russia. The first heavy snowfall followed a few days later and from 29 December until early March the ground was continuously snow-covered over most of the country. The most outstanding feature was the long duration of the cold weather rather than its absolute severity ; few individual low temperature records were broken. January was the coldest month and the most severe weather occurred in its third week. The winter was also remarkable for the heavy snowfalls which were piled into deep drifts by the strong easterly winds and which brought traffic to a standstill in many areas, isolating villages and farms in some cases for weeks on end. The worst blizzards were those of 29 December and 3 January in southern and south-western districts, 16–18 January in north-east England, and 4–5 February, again mainly in south-west England and south Wales. The cold weather came to an end on 4–6 March as a mild south-westerly airstream spread in from the Atlantic.

A general account. Table I summarizes conditions during the winter (December to February inclusive) at 16 selected stations, 10 in England and Wales, 4 in Scotland and 2 in Northern Ireland and includes some of the extreme values that were recorded.

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TABLE I—CLIMATOLOGICAL DATA FOR THE 1962–63 WINTER AT SELECTED STATIONS IN THE UNITED KINGDOM
(DECEMBER–MARCH UNLESS OTHERWISE INDICATED)

	Middleton St George	West Raynham	Rothamsted	Elmdon	Heathrow	Kew	Stonyhurst	Ringway	Rhoose	Mount Batten	Dyce	Turnhouse	Edinburgh, Blackford Hill	Renfrew	Aldergrove	Armagh
TEMPERATURE (°C)																
Mean December	0·7	1·5	0·9	2·1	2·2	2·8	1·7	2·3	3·2	5·5	2·3	2·7	3·1	3·0	4·0	4·2
Departure*	(−3·5)	−2·7	−3·0	−2·3	−2·7	−2·6	−2·6	−2·2	−2·0	−1·7	−1·4	−1·5	−1·5	−1·4	−0·9	−0·9
Mean January	−0·6	−2·4	−3·3	−2·8	−1·9	−1·1	−1·3	−1·4	−2·2	−0·2	−0·6	0·1	0·1	−0·1	−0·5	−0·3
Departure*	(−3·5)	−5·2	−6·1	−6·0	−5·7	−5·4	−4·3	−4·8	−6·8	−6·4	−3·0	−2·7	−3·1	−3·2	−4·2	−4·4
Mean February	−1·1	−1·7	−1·7	−1·2	0·3	0·4	−0·7	−0·1	−0·2	2·4	−0·3	−0·6	−0·1	0·3	0·9	1·2
Departure*	(−5·0)	−4·9	−4·9	−4·7	−4·0	−4·2	−4·0	−3·8	−4·6	−3·4	−3·2	−4·0	−3·6	−3·6	−3·3	−3·4
Mean Winter	−0·3	−0·9	−1·4	−0·6	0·2	0·7	−0·1	0·3	0·3	2·6	0·5	0·7	1·0	1·1	1·5	1·7
Departure*	(−4·0)	−4·3	−4·7	−4·3	−4·1	−4·1	−3·6	−3·6	−4·5	−3·8	−2·5	−2·7	−2·7	−2·7	−2·8	−2·9
Lowest minimum	−14·2	−13·0	−16·7	−16·0	−12·3	−9·7	−10·6	−11·4	−9·7	−6·5	−12·0	−14·1	−6·7	−13·8	−10·6	−11·1
Date	29/12	24/1	23/1	23/1	23/1	25/1	12/1	29/12	12/1	14/1	23/1	3/2	17/1†	13/1	23/1	24/1
Lowest maximum	−4·0	−4·8	−5·0	−4·4	−5·2	−2·8	−2·2	−6·2	−5·2	−2·5	−5·5	−3·6	−2·8	−6·1	−3·5	−0·5
Date	28/12	25/1	24/1	24/1	25/1	24/1	22/1	12/1	25/1	11/1	17/1	17/1	12/1	12/1	13/1	12/1
Number of days with air frost	74	80	77	76	70	61	71	73	67	49	62	64	62	61	56	60
Max. number of consecutive days with air frost	20	24	36	25	20	20	21	21	21	20	17	17	18	11	13	22
Period beginning	13/2	9/2	23/12	8/2	7/1	7/1	6/1	7/1	7/1	7/1	16/2	16/2	16/2	22/2	17/1	8/1
Number of ice days	14	28	31	29	16	15	9	14	27	7	10	6	6	3	1	1
Max. number of consecutive ice days	4	7	8	7	7	9	4	6	9	3	2	3	2	1	1	1
Period beginning	22/1	19/1	17/1	28/12	19/1	17/1	20/1	19/1	17/1	17/1	6/1 11/1 16/1	11/1	11/1	12/1 17/1 22/1	13/1	12/1

*Departure from 1931–60 average. †Lowest minimum temperature also occurred on 23/1 and 3/2.

The figures in brackets are estimated. Temperatures are in degrees Celsius.

Note. The names of stations in Tables I, II and VI are in accordance with the climatological names used in the London, Meteorological Office, *Monthly Weather Report*, London, H.M.S.O.

The names in Tables III, IV ,V and VII refer to long period series of observations.

TABLE I—CLIMATOLOGICAL DATA FOR THE 1962–63 WINTER AT SELECTED STATIONS IN THE UNITED KINGDOM (DECEMBER–MARCH UNLESS OTHERWISE INDICATED)—*contd.*

	Middleton St George	West Raynham	Rothamsted	Elmdon	Heathrow	Kew	Stonyhurst	Ringway	Rhoose	Mount Batten	Dyce	Turnhouse	Edinburgh, Blackford Hill	Renfrew	Aldergrove	Armagh
PRECIPITATION																
December rainfall*	(105)	110	99	73	99	111	112	113	61	96	102	109	92	103	93	111
January rainfall*	(70)	47	43	39	23	36	11	15	60	19	63	71	76	15	34	47
February rainfall*	(70)	38	41	39	16	41	11	9	54	100	67	65	33	14	69	112
Maximum depth of level snow (cm)	15	10	38	15	18	20	8	8	20	13	15	14	15	9	20	15
Date	28/12, 8/2	20/1, 4/2	3/1	2/2, 3/2	3/1	1/1	2/2	20/1, 3/2	3/1	30/12	31/12, 1/1	2/1	31/12	25/12	7/2	6/2
Total number of days with snow lying at 0900 GMT :																
All depths	61	60	66	52	42	45	65	35	51	15	55	38	55	9	17	36
5 cm or more in depth	51	25	62	40	18	26	–	8	12	5	27	14	47	2	11	19
Total number of days with snow or sleet falling	49	48	37	44	43	48	–	35	31	32	51	42	36	32	43	30
SUNSHINE																
December†	(145)	(205)	182	133	–	171	184	219	(120)	129	99	111	101	139	97	102
January†	(130)	(170)	110	165	–	107	165	200	(140)	156	94	88	77	116	121	122
February†	(75)	(105)	100	106	–	112	162	177	(110)	115	119	158	115	131	130	109
WIND																
Number of days with wind from NE, E or SE at 0900 GMT :																
December	2	8	–	9	10	9	–	8	16	14	3	4	–	4	9	–
January	13	18	–	17	13	16	–	17	26	23	8	15	–	16	18	–
February	8	17	–	15	16	17	–	15	23	17	6	10	–	14	18	–

*Percentage of 1916–50 average. †Percentage of 1931–60 average. The figures in brackets are estimates.

Sleet is precipitation of snow and rain together, or of snow melting as it falls.

Air temperatures. Air temperatures were at their lowest from about 23 December to 25 January the last part of this period being exceptionally cold with continuous frost in many places from 17–25 January. After a brief less-cold interlude there was another severe spell early in February, the generally cold weather continuing until early March.

December 1962 was cold with mean temperatures ranging from about 1 to 3 degC below average. January, 1963 was exceptionally cold with anomalies of mean temperature ranging from – 2 to – 7 degC. It was the coldest January on record at such long-period stations as Oxford (1815), Plymouth (1865), Edgbaston (1887), Cambridge (1871) and Braemar (1866). (The year quoted in brackets after each station gives the date of the beginning of the period of observations available.) It was the coldest January at Kew since 1838 and at Armagh since 1881, but at Durham and Stonyhurst, January 1940 was colder, while at Edinburgh there have been 18 colder Januarys since 1765, the most recent being that of 1895. February 1963 was not quite so outstanding with anomalies of – 3 to – 5 degC, but it was the coldest February on record at Plymouth and in the last 90 years or so has been beaten for coldness only by the Februarys of 1947 and 1895 at such long-period stations as Cambridge, Kew, Stonyhurst, Oxford, Edinburgh, Braemar and Armagh. Anomalies of winter mean temperature ranged from about –2·5 to –4·5 degC, but comparisons of the winter as a whole with earlier winters will be made later on in the article.

Table II lists some of the lowest minimum air temperatures recorded in the 1963 winter at stations with reasonably long records, together with the lowest recorded values at these stations. The lowest recorded 1963 temperatures were – 22·2°C (– 8°F) at Braemar on 18 January and – 20·6°C (– 5°F) at Stansted Abbotts on 23 January. As the table shows, temperatures below – 10°C occurred widely in mid-January and even on coasts and in the Channel Islands temperatures fell well below – 5°C.

TABLE II—EXTREME MINIMUM TEMPERATURES OF 1963 WINTER AND LOWEST RECORDED VALUES AT SELECTED STATIONS

Station	Lowest minimum (°C) in 1963 winter and date of occurrence	Lowest minimum (°C) on record and year of occurrence
Strathy	– 12·8 (12.1.63)	– 15·0 (1947)
Braemar	– 22·2 (18.1.63)	– 27·2 (1895)
Onich	– 8·9 (13.1.63)	– 11·1 (1940, 1961)
Eskdalemuir	– 15·7 (13.1.63)	– 18·5 (1961)
Houghall	– 15·6 (23, 24.1.63)	– 22·1 (1941, 1947)
Lincoln	– 14·4 (22.1.63)	– 16·1 1956)
Cambridge Bot. Gdn.	– 16·1 (23, 24.1.63)	– 17·2 (1947)
Woburn	– 20·0 (23.1.63)	– 20·6 (1947)
Wakefield	– 15·0 (23.1.63)	– 15·0 (1940)
Shawbury	– 18·2 (23.1.63)	– 19·4 (1958)
Wisley	– 13·9 (13.1.63)	– 15·0 (1917)
Stonyhurst	– 10·6 (12.1.63)	– 13·9 (1940)
Aberystwyth (P.B.S.)	– 8·9 (12.1.63)	– 11·1 (1929, 1940)
Haverfordwest	– 13·9* (13.1.63)	– 12·8 (1958)
Bath	– 13·9 (23.1.63)	– 15·6 (1947)
Exeter	– 11·7 (14.1.63)	– 15·0 (1958)
Penzance	– 6·7 (14.1.63)	– 8·3 (1947)
Moneydig	– 11·7 (13.1.63)	– 16·7 (1945)
Armagh	– 11·1 (24.1.63)	– 12·2 (1947)
St Helier	– 8·3 (20.1.63)	– 8·3 (1948)

* New record.

There were, as shown in Table I, many days (ice days) when the temperature failed to rise to the freezing-point. At many places in England temperatures remained continuously below freezing for a week or more between 17 and 25 January. The coldest days were 29 December, 12, 13, 17, 19, 23, 24 and 25 January.

Earth temperatures. The frost penetrated deeply into the ground and temperatures at a depth of 1 foot fell to below 0°C in many areas, stations so affected including Edinburgh, York, Terrington St Clement, Cambridge, Huddersfield, Bradford, Nottingham, Raunds, Oxford, Kew, Porton, and Newton Rigg. The lowest values at this depth were reached in most places in late January or early February but at a few stations, mostly in the west and north, the minimum was delayed until late February or early March. At Edinburgh (Royal Botanic Gardens), for example, the minimum of −0·3° C occurred on 4 March and at Ross-on-Wye 0·4° C was reached on 5 March. The lowest value recorded was −3·2°C at Oxford on 24 January, the previous lowest there being −1·4°C in January, 1940. New record low temperatures at 1 foot were also established at Edinburgh, York, Hull, Gorleston, Nottingham, Raunds, Kew, Margate, Hastings, Southsea, Plymouth and Armagh but at other stations, namely, Cranwell, Rothamsted, Huddersfield, Bradford, Ross-on-Wye and Bath, the low values of January 1940 were not reached.

Earth temperatures at 4 feet did not attain their lowest values until late February or early March. The lowest recorded was 0·9°C at Nottingham and new record minimum values were established at many other stations also. However, there were many stations at which the record low values of March 1947, were not attained.

When considering these earth temperatures it has to be borne in mind that they are measured under a grass-covered surface from which snow is not removed. Frost penetration will be greater at places where there is no snow cover or where it has disappeared. Under roads and pavements earth temperatures are likely to be lower than under grass especially when these are cleared of snow.

Rainfall and snow. The 1963 winter was not one of high rainfall (rainfall includes precipitation of all types), totals being well below the average in all areas. January was a particularly dry month, being the driest January over England and Wales since 1881. February was also very dry, especially in north-west England. The winter as a whole was considerably drier than the last severe winter of 1947, which was described by Douglas[2] as 'the snowiest of which we have any precise knowledge'.

Nevertheless there were some heavy falls of snow particularly in south-west England and south Wales, where conditions were probably at least as bad as in 1947. Many places in southern England were under 30 centimetres (12 inches) of undrifted snow at the beginning of January, Princetown and Tredegar having 18 and 32 inches, respectively. By early February most parts of central and southern England still had 6 to 9 inches of snow and parts of northern and south-west England and south Wales over 12 inches, Tredegar reporting 65 inches and Spadeadam 25 inches. At the beginning of March, snow had disappeared from many southern and western areas but was still 2 to 3 inches deep in parts of Bedfordshire, Sussex, Wiltshire and

Gloucestershire and much of north-east England was covered to a depth of 12 inches or more, Bellingham having 30 inches. In drifts the depths of snow were of course much greater, 10–15 feet being fairly common and drifts 25 feet deep being reported from the south-west in January.

The long duration of the wintry weather was reflected in the large total numbers of days on which snow lying was reported. These ranged from about 10 in south-west coast districts to nearly 80 in central Scotland with 45 days at Kew, 66 at Cambridge, 67 at Oxford, 69 at Stonyhurst, 55 at Edinburgh and 36 at Armagh. The ground was snow-covered throughout January and February over most of the United Kingdom. Snow or sleet fell on 49 days at Kew, 18 at Plymouth, 23 at Cambridge, 37 at Oxford, 36 at Manchester/Ringway, 36 at Edinburgh and 31 at Armagh, during December to March inclusive.

Sunshine. In spite of the severe weather, the winter of 1963, in contrast to that of 1947, was by no means a dull one, sunshine amounts being well above average everywhere. In December, only Northern Ireland had slightly less than the average and a number of places in south-east and northern England had more than twice the average. Apart from eastern Scotland, January was everywhere sunnier than average, being particularly sunny in north-west Scotland, north-west and south-west England and Wales. At Newquay it was the sunniest January on record and at Stornoway the sunniest since 1881. Although a little less sunny than normal in the Midlands and north-east England, February had above-average amounts of sunshine in all other districts, being particularly sunny in north-west England, where Stonyhurst had its sunniest February on record, and in west and north Scotland. Sunny weather continued until the end of the cold weather in early March.

Wind. As Table I shows, the winter was characterized by an unusually high frequency of easterly winds, especially during January and February. Easterly gales were widespread on 19–20 January and also occurred over a large area in the north and west on 5–6 February.

Comparison with earlier severe winters.

Mean winter temperature. The longest series of temperature records available for the United Kingdom are those for central England from 1698[1] and Edinburgh from 1765.[3] In the former series the only winter (December to February inclusive) colder than 1963 is that of 1740. In the latter, however, there are seven colder winters than that of 1963, the most severe being that of 1780.

Table III gives details of the 20 coldest winters since 1765, in order of severity, for central England and for Edinburgh. The same information is given for $\frac{1}{2}$ (central England + Edinburgh) in the right-hand side of the table and may be regarded as the probably best available estimate of the relative severity of cold winters over the United Kingdom as a whole in the past 200 years. While 1963 heads the list it is interesting to note that only 2 out of the first 10 and 3 out of all 20 of these severe winters have occurred in the present century.

It is important to consider whether or not the 1963 winter is so exceptional that some special cause for it might have to be sought. Some light can be

TABLE III—THE 20 COLDEST WINTERS, WITH AVERAGE TEMPERATURES, SINCE 1765 IN CENTRAL ENGLAND AND IN EDINBURGH, IN ORDER OF SEVERITY

Central England		Edinburgh		½ (Central England + Edinburgh)	
Year	Temperature °C	Year	Temperature °C	Year	Temperature °C
†*1963	−0·3	1780	0·1	†*1963	0·4
1814	0·4	*1879	0·2	*1879	0·4
1795	0·5	1814	0·6	1814	0·5
*1879	0·7	1838	1·0	1780	0·7
†*1947	1·1	1860	1·0	1795	0·8
1830	1·1	1823	1·1	1838	1·2
*1895	1·2	1795	1·1	1823	1·3
1784	1·2	†*1963	1·2	*1895	1·3
1766	1·3	*1881	1·2	†*1947	1·3
1785	1·4	1774	1·3	1784	1·3
1780	1·4	1820	1·4	1820	1·4
1838	1·4	*1895	1·4	1766	1·5
1820	1·4	1784	1·5	1785	1·5
†*1940	1·4	†*1947	1·5	1830	1·5
*1891	1·5	1809	1·6	1845	1·6
†*1917	1·5	1766	1·6	1860	1·6
1845	1·5	1776	1·7	*1881	1·7
1823	1·6	1785	1·7	1847	1·8
1841	1·6	1816	1·7	†*1940	1·9
1847	1·7	1845	1·7	1841	1·9

*Within the last 100 years.
†20th century

thrown on this point by a statistical examination of the 268 winter mean temperatures provided by the central England series. Their statistical distribution is one that departs very appreciably from normal, being rather flat with long tails, particularly at the low temperature end. Their mean value is 3·77°C and standard deviation (σ) 0·66 degC. There are 25 and 9 winters, respectively, with mean temperatures 3σ or more and 4σ or more below the mean and 12 and 2 winters respectively which are these amounts above the mean. In these circumstances the probability of the 1963 mean winter temperature cannot be adequately assessed on the basis of the normal distribution. However, the statistical theory of extreme values may be applied to the series consisting of the lowest mean winter temperature in each of the 26 decades. When this is done for the decades 1701–10 to 1951–60, i.e. excluding consideration of the 1963 winter, it is found that the return period of a winter with mean temperature −0·3°C (that of the 1963 winter) is 20 decades. Thus such a winter could (in 1962), have been expected to have occurred on the average once in 20 decades. When the computations are repeated for the decades 1706–15 to 1956–65, thus including the 1963 winter, the return period for such a winter is naturally a little shorter and comes out as 15 decades. These extreme value distributions are shown plotted on extreme-value probability paper in Figure 1 from which it is evident that the data are reasonably well fitted by a straight line and that the 1963 winter is well within the population of other cold winters that have been experienced in this country.

There are few stations currently reporting whose records go back more than about 100 years and if it is desired to compare severe winters on a wider geographical or more detailed basis then one is restricted to this length of period. Table III suggests that for such a comparison attention may be confined to the winters of 1963, 1879, 1895 and 1947, perhaps adding 1940,

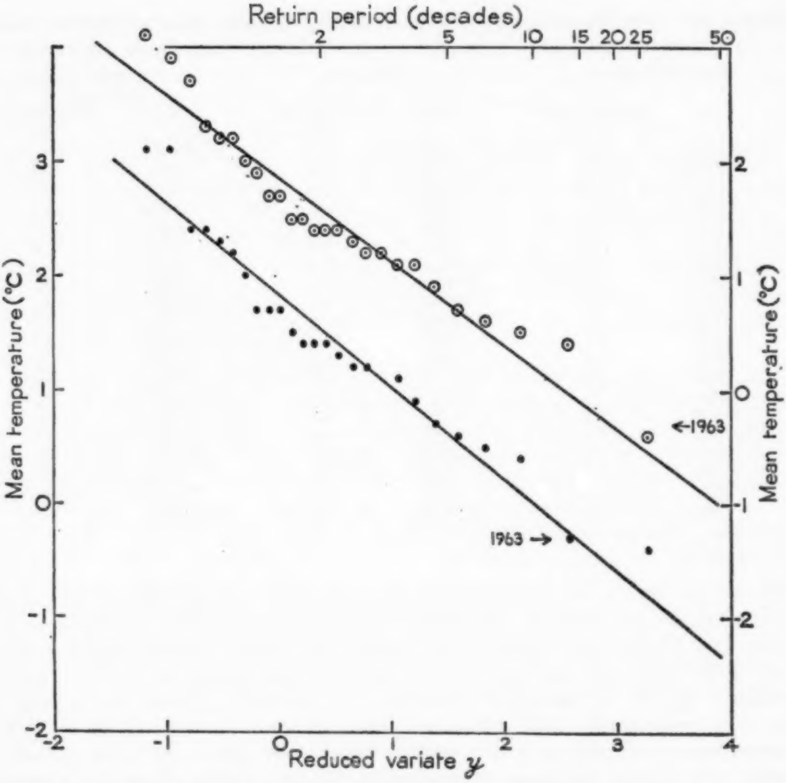

FIGURE 1—DISTRIBUTION OF LOWEST MEAN WINTER TEMPERATURES IN EACH DECADE FOR CENTRAL ENGLAND

The mean temperatures are the lowest mean winter temperatures of the decades. The extreme probability graph paper has a uniform scale along the vertical axis for the chosen mean temperatures. The horizontal scale is the probability scale and is marked according to the formula $y = -\log_e(-\log_e p)$, where $p = m/(n+1)$, m being the ranking of the mean temperature arranged in order of size from the smallest to the largest, n being the number of observations. (The reduced variate y can be plotted on the linear scale of ordinary graph paper.) The return period in decades is $1/(1-p)$. The upper curve is for decades 1701–10 to 1951–60 (right-hand temperature scale). The lower curve is for decades 1706–15 to 1956–65 (left-hand temperature scale).

because it was the third most severe winter this century, and 1891, because it was almost as severe as 1947 over a large part of southern England and the Midlands.

Table IV gives the mean temperatures and years of occurrence of the 10 coldest winters, in order of rank, in the last 100 years at a number of long-period stations. Figures for the central England series are included for comparison. The records for Armagh and Cambridge began in 1871. Those for Kew have been adjusted for the effects of urbanization by subtracting a correction which increases linearly from nil in 1877 to 0·7 degC in 1963, this correction having been established on the basis of a comparison of the Kew winter temperatures from 1873 onwards with those recorded at

TABLE IV—THE 10 COLDEST WINTERS SINCE 1865 IN RANKING ORDER, AT EIGHT LONG-PERIOD STATIONS, AND N CENTRAL ENGLAND

Kew		Cambridge		Oxford		Stonyhurst		Plymouth	
Year	Mean Temp. °C	Year	Mean Temp. °C	Year	Mean Temp. °C	Year	Mean Temp. °C	Year	Mean Temp. °C
1963	−0·1	1963	−0·8	1963	−1·1	1963	−0·1	1963	1·2
1947	0·9	1947	0·7	1947	0·7	1879	0·1	1879	3·4
1891	1·0	1891	0·8	1891	0·8	1895	0·9	1947	3·4
1929	1·6	1895	0·9	1879	1·1	1947	1·1	1917	3·6
1895	1·6	1879	1·0	1895	1·2	1940	1·1	1895	3·8
1879	1·7	1940	1·1	1940	1·3	1917	1·6	1891	3·8
1940	1·7	1929	1·3	1929	1·4	1929	1·6	1886	4·1
1942	2·0	1917	1·6	1917	1·5	1881	1·6	1888	4·3
1917	2·1	1886	1·7	1942	1·9	1891	1·9	1934	4·6
1880	2·2	1942	1·8	1880	2·3	1886	1·9	1887	4·7

Edinburgh		Braemar		Armagh		Central England	
Year	Mean Temp. °C	Year	Mean Temp. °C	Year	Mean Temp. °C	Year	Mean Temp. °C
1879	0·2	1895	−2·7	1879	0·2	1963	−0·3
1963	1·2	1963	−2·4	1895	1·7	1879	0·7
1881	1·2	1879	−1·6	1963	1·7	1947	1·1
1895	1·4	1881	−1·4	1881	1·8	1895	1·2
1947	1·5	1947	−1·2	1947	2·4	1940	1·4
1870	2·3	1929	−0·6	1917	2·9	1891	1·5
1940	2·3	1900	−0·6	1941	2·9	1917	1·5
1886	2·4	1940	−0·5	1951	2·9	1929	1·7
1941	2·4	1941	−0·4	1873	3·2	1942	2·2
1951	2·4	1936	−0·3	1936	3·2	1881	2·2

Rothamsted over the same period. The Edinburgh mean temperatures are reduced to a height of 250 ft and are taken from Thomson.[3] Those for Oxford are reduced to mean-of-day* values, in continuation of the values published for 1815 to 1935.[4]

Table V gives for the same set of stations, and on the same basis, the mean temperatures of December 1962, January 1963, February 1963, January and February 1963 combined, and the winter as a whole, together with the mean temperatures and date of the previous coldest corresponding period on record. The year of commencement of record is given below the station name in each case and where the 1963 temperatures constituted a new record they are marked with an asterisk.

Snow and snow lying. Statistics relating to snow are notoriously difficult to deal with and observations are often unreliable or missing because of the difficulties of measurement, particularly in the earlier years.

The available data make it fairly certain, however, that for general snowiness over the United Kingdom as a whole, 1947 was the worst winter in the past 100 years or more. It was considerably more snowy than 1895 or 1940. Thus in order to put the 1963 winter in perspective in this respect it is probably sufficient to make comparisons with 1947 and in any case this is all that can be done with any degree of reliability.

Table VI presents total numbers of days in December to March inclusive with snow falling and with snow lying at selected representative stations

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* i.e. the mean of maximum plus minimum was adjusted to be comparable with the mean-of-day values, which were the average of observations at 0900, 1200 and 2100 clock time.

TABLE V—MEAN MONTHLY AND SEASONAL TEMPERATURES AT SELECTED LONG-PERIOD STATIONS IN THE 1963 WINTER TOGETHER WITH DETAILS OF THE COLDEST CORRESPONDING VALUES PREVIOUSLY RECORDED

	Kew (1783)	Cambridge (1871)	Oxford (1815)	Stonyhurst (1848)	Plymouth (1865)	Edinburgh (1765)	Braemar (1866)	Armagh (1871)	Central England (1698)
DECEMBER									
Mean temperature 1962 (°C)	2·0	1·1	1·2	1·7	5·4	3·2	1·1	4·2	1·8
Previous coldest (°C)	−1·2	−2·2	−1·6	−0·9	2·1	−0·5	−2·1	−1·8	−0·8
Year	1890	1890	1890	1878	1878	1878	1874	1878	1890
JANUARY									
Mean temperature 1963 (°C)	−1·8	−2·7*	−3·2*	−1·3	−0·2*	0·2	−4·7*	−0·2	−2·1
Previous coldest (°C)	−2·6	−1·5	−1·8	−1·6	1·3	−3·1	−4·0	−1·3	−3·1
Year	1795	1940	1838	1881	1881	1814	1895	1881	1795
FEBRUARY									
Mean temperature 1963 (°C)	−0·5	−0·9	−1·1	−0·7	−1·7*	0·1	−3·8	1·2	−0·7
Previous coldest (°C)	−1·6	−1·9	−2·6	−1·9	0·5	−1·4	−5·8	−0·5	−1·9
Year	1895	1947	1947	1855	1947	1947	1895	1895	1947
JAN. and FEB.									
Mean temperature 1963 (°C)	−1·2*	−1·8*	−2·2*	−1·0	−0·9*	0·2	−4·3	0·5	−1·4
Previous coldest (°C)	−0·3	−0·8	−0·8	−1·1	1·7	−1·0	−4·9	−0·2	−2·2
Year	1895	1895	1895	1895	1895	1838	1895	1895	1740
WINTER									
Mean temperature 1963 (°C)	−0·1*	−0·8*	−1·1*	−0·1*	1·2*	1·2	−2·4	1·7	−0·3
Previous coldest (°C)	0·9	0·7	0·7	0·1	3·4	0·1	−2·7	0·2	−0·4
Year	1947	1947	1947	1879	1879	1780	1895	1879	1740

* New record

The year quoted in brackets below each station gives the dates of the beginning of the period of observations available.

during the winters of 1947 and 1963. Days with snow lying to a depth of 6 cm or more are given as well as those with snow lying regardless of depth.

The snow-falling figures suggest that the two winters were rather similar in this respect but taken in conjunction with the total rainfall figures discussed earlier, it is considered that the total amount of snow which fell in 1963 must have been appreciably less than that in 1947, although there were undoubtedly some areas, notably in the south-west, where 1963 gave more snow.

Days with snow lying were decidedly more frequent in 1963 at the majority of stations and this is a reflection of the unusually long duration of the cold weather. When numbers of days with snow depths exceeding 5 cm are considered, however, this difference vanishes and if anything the figures suggest that 1947 was more snowy than 1963, in conformity with the more reliable indications of the total rainfall figures. Certainly there was more snow on the ground in 1947 over a large area of eastern England and the Midlands.

TABLE VI—NUMBERS OF DAYS WITH SNOW FALLING AND SNOW LYING AT SELECTED STATIONS IN THE WINTERS (DECEMBER–MARCH) OF 1947 AND 1963

Station	Days with snow falling		Days with snow lying			
			All depths		Depths of 6 cm or more	
	1947	1963	1947	1963	1947	1963
Balmoral	28	48	70	79	54	71
Eskdalemuir	59	49	58	73	48	69
Acklington	46	50	49	59	41	33
Finningley	52	41	54	50	49	21
West Raynham	44	50	55	60	49	19
Edgbaston	46	38	57	68	56	45
South Farnborough	44	38	38	58	8	13
Ringway	48	36	17	35	0	5
Aberporth	24	31	20	31	8	13
Mount Batten	21	32	7	15	3	4
Aldergrove	37	43	26	17	7	8

Cold spells in 1963 and in earlier severe winters. So far attention has been largely confined to complete months and combinations thereof. It is interesting also to compare the 1963 winter with earlier ones in terms of the severity of cold spells of various lengths, from 1 day upwards.

For this comparison attention has been directed to six severe winters, those of 1879, 1891, 1895, 1940, 1947 and 1963 (see Table III), and to daily values of temperature at four stations, Kew, Edinburgh, Stonyhurst and Armagh.

Table VII presents the results of the analysis giving the mean temperature of the coldest spells of length 1, 3, 5, 7, 10, 15, 20, 25 . . . 90 days at each station and in each winter, attention being restricted to spells having mean temperatures below 0°C. The coldest spell of each length at each station is printed in bold.

At Kew the coldest single day occurred in 1891; 1895 had the coldest spells with lengths from 3 to 25 days inclusive, 1891 had the coldest of 30 to 45 days inclusive and also that of 55 days, while 1963 included the most severe spells of lengths 50 days and 60 to 85 days inclusive. Stonyhurst shows a similar pattern with 1895 having the most severe spells of 30 days or less and 1963 becoming predominant for sub-freezing spells of 45–90 days inclusive. At both Edinburgh and Armagh on the other hand 1963 failed to produce the coldest spells of any length in the winters considered. At Edinburgh,

TABLE VII—MEAN TEMPERATURES, IN DEGREES BELOW 0°C, OF COLDEST SUB-FREEZING SPELLS AT KEW, STONYHURST, EDINBURGH AND ARMAGH DURING SIX VERY COLD WINTERS

Length of spell	KEW* 1879	KEW* 1891	KEW* 1895	KEW* 1940	KEW* 1947	KEW* 1963	STONYHURST† 1879	STONYHURST† 1891	STONYHURST† 1895	STONYHURST† 1940	STONYHURST† 1947	STONYHURST† 1963
days							*degrees Celsius below 0°C*					
1	5·6	**8·4**	8·1	6·3	6·4	6·6	6·2	5·6	**8·3**	7·5	4·5	5·6
3	4·2	6·6	**7·7**	4·0	4·3	6·0	5·3	4·7	**7·7**	6·1	4·2	4·7
5	3·0	4·0	**6·9**	4·1	3·8	5·0	4·6	3·5	**6·8**	4·9	3·4	4·0
7	2·1	3·4	**5·9**	3·5	3·2	4·6	4·1	2·5	**5·9**	4·9	3·1	3·4
10	1·6	3·3	**5·3**	3·0	3·1	4·1	3·3	2·7	**5·5**	3·9	2·7	3·2
15	1·7	3·0	**4·1**	2·4	2·8	3·7	3·6	1·9	**3·8**	3·1	2·4	3·3
20	1·3	2·7	**3·7**	1·9	2·3	3·0	2·7	1·1	**3·6**	2·3	2·3	2·6
25	0·4	2·4	**3·2**	1·5	1·9	2·5	1·6	0·9	**3·0**	2·1	2·0	2·0
30		**2·6**	2·5	0·8	2·1	2·3	1·2	0·9	**2·5**	1·5	2·0	2·0
35		**2·3**	1·8	0·8	1·9	2·0	1·3	0·7	1·9	1·4	2·0	**2·0**
40		**2·1**	1·3	0·7	1·7	1·8	0·9	0·6	1·9	1·4	**1·9**	1·6
45		**1·8**	0·9	0·5	1·6	1·8	0·8	0·4	1·7	0·9	1·6	**1·7**
50		1·3	0·7	0·3	1·3	**1·6**	0·9	0·1	1·5	1·0	1·5	**1·5**
55		**1·4**	0·4	0·2	0·9	1·3	0·8		1·3	1·0	1·2	**1·4**
60		1·1	0·3	0·2	0·4	**1·3**	0·7		1·1	0·6	0·9	**1·4**
65		0·5	0·1	0·1		**1·2**	0·4		0·9	0·4	0·3	**1·3**
70						**1·1**	0·1		0·6	0·1	0·2	**1·2**
75						**0·8**			0·3			**0·9**
80						**0·4**						**0·6**
85						**0·1**						**0·3**
90												**0·2**

Length of spell	EDINBURGH† 1879	EDINBURGH† 1891	EDINBURGH† 1895	EDINBURGH† 1940	EDINBURGH† 1947	EDINBURGH† 1963	ARMAGH† 1879	ARMAGH† 1891	ARMAGH† 1895	ARMAGH† 1940	ARMAGH† 1947	ARMAGH† 1963
days	*degrees Celsius below 0°C*											
1	**7·1**	2·3	6·5	4·8	4·5	3·7	**8·4**	5·2	8·1	5·6	5·0	4·7
3	4·7	1·3	**5·8**	3·3	2·7	2·8	6·0	2·5	**6·1**	3·3	2·6	3·6
5	4·0	1·2	**5·5**	2·7	2·3	2·2	4·2	1·3	**5·5**	3·3	2·1	2·5
7	3·1	0·3	**4·8**	2·7	2·2	1·6	3·4	0·5	**5·0**	3·0	1·6	1·6
10	2·4	0·1	**4·1**	1·6	2·1	1·2	3·0		**3·5**	2·5	1·5	1·1
15	2·5		**2·9**	0·9	1·9	1·1	**3·1**		2·6	0·8	1·3	1·5
20	2·1		**2·5**	0·6	1·8	0·7	**2·6**		2·1		1·0	1·0
25	1·5		**2·0**		1·7	0·4	**1·7**		1·7		0·6	0·8
30	1·1		1·5		**1·7**	0·4	1·0		**1·3**		0·5	0·5
35	1·1		1·1		**1·6**	0·2	0·8		**0·9**		0·4	0·3
40	1·0		1·0		**1·6**	0·1	0·5		**0·8**		0·3	0·5
45	0·8		0·9		**1·5**	0·1			**0·7**		0·1	0·3
50	0·8		0·9		**1·3**	0·1			**0·7**			0·1
55	0·7		0·7		**1·1**	0·1			**0·5**			
60	0·7		0·3		**0·8**				**0·2**			
65	**0·5**		0·1		0·4							
70	0·2											
75												
80												
85												
90												

*Based on means of hourly values and corrected for effect of urbanization.

†Based on means of ½ (maximum + minimum), Edinburgh values reduced to height of 250 feet.

The coldest spell of each length at each station is printed in bold.

1895 was outstanding for shorter severe spells with 1947 and 1879 sharing the longer ones. At Armagh, 1879 was predominant for spells of 1 day and 15 to 25 days inclusive and 1895 for the remainder, including those of 30 to 60 days inclusive.

Conclusions. The 1963 winter was probably the coldest over most of England and Wales since 1740, over Scotland since 1879 and over Northern Ireland since 1895. It was particularly notable for the long duration of the cold weather and for the depth to which frost penetrated the ground, especially where snow disappeared early or was removed, rather than for the severity of individual days. Statistical examination of the data has shown that the 1963 winter was not outside the population of other winters and that it is not necessary therefore to seek some very special cause in order to explain it. The above-average sunshine, particularly in January, provided some mitigation of the cold easterly winds. Although there were some very heavy snowfalls causing widespread inconvenience and disrupting communications, the overall amount of snow was probably less than in 1947, the snowiest winter for which we have reliable records.

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SOME ASSOCIATIONS BETWEEN MONTHLY RAINFALL OVER ENGLAND AND WALES AND CENTRAL ENGLAND TEMPERATURES

By R. MURRAY

Summary. The synchronous associations between monthly rainfall over England and Wales and monthly mean temperature over central England are presented in contingency tables. Some non-synchronous relationships which are likely to be useful in long-range prediction are also discussed.

Introduction. It is well known that there is a tendency in summer months for low (high) rainfall to be associated with high (low) temperatures (i.e. an inverse relationship) and in the winter months for low (high) rainfall to be associated with low (high) temperatures (i.e. a direct relationship), but the synchronous association is not self-evident in spring and autumn months. Moreover, the monthly rainfall over an area the size of England and Wales seems likely to have some significance in terms of large-scale circulation and consequently in rainfall and temperature prediction. From other investigations long-period data were available (i) for England and Wales rainfall in terciles[1] (tercile 1 being low rainfall) and (ii) for central England[2] temperatures in quintiles[3] (quintile 1 being much below average) so that the synchronous associations and the non-synchronous associations (i.e. those with a possible predictive value) between monthly rainfall and monthly temperatures were readily obtainable with the help of a small computer-programme. The results that are of practical use are presented briefly in this note. The tercile and quintile limits for monthly rainfall and temperature are stated in references 1 and 3.

Synchronous associations. All the synchronous associations are of interest and are presented in Table I.

TABLE I—SYNCHRONOUS ASSOCIATIONS BETWEEN ENGLAND AND WALES MONTHLY RAINFALL (TERCILES) AND CENTRAL ENGLAND MONTHLY MEAN TEMPERATURES (QUINTILES) FOR THE 90-YEAR PERIOD DECEMBER 1873 TO NOVEMBER 1963

	Temperature quintile						Temperature quintile						Temperature quintile				
	Dec.	1	2	3	4	5	Jan.	1	2	3	4	5	Feb.	1	2	3	4	5
		No. of years						*No. of years*						*No. of years*				
Rainfall tercile	1	8	9	5	6	1	1	9	8	6	2	5	1	11	9	4	3	2
	2	8	6	8	3	6	2	7	6	6	7	6	2	6	4	5	5	11
	3	2	2	8	8	10	3	3	4	6	8	7	3	1	6	9	8	6
	Significant at 2·5 per cent level						Not significant						Significant at 1 per cent level					
	Mar.	1	2	3	4	5	Apr.	1	2	3	4	5	May	1	2	3	4	5
		No. of years						*No. of years*						*No. of years*				
Rainfall tercile	1	6	6	6	7	7	1	6	6	5	6	9	1	3	6	9	3	9
	2	5	6	5	5	6	2	6	4	4	6	5	2	6	5	5	8	8
	3	7	5	7	5	7	3	7	8	8	7	3	3	8	8	4	7	1
	Not significant						Not significant						Not significant					
	June	1	2	3	4	5	July	1	2	3	4	5	Aug.	1	2	3	4	5
		No. of years						*No. of years*						*No. of years*				
Rainfall tercile	1	4	5	8	3	11	1	3	3	3	8	12	1	3	0	5	8	12
	2	5	5	8	6	6	2	7	5	4	7	6	2	5	4	10	6	5
	3	10	8	1	9	1	3	9	10	10	3	0	3	11	13	4	3	1
	Significant at 1 per cent level						Significant at 0·2 per cent level						Significant at 0·1 per cent level					
	Sept.	1	2	3	4	5	Oct.	1	2	3	4	5	Nov.	1	2	3	4	5
		No. of years						*No. of years*						*No. of years*				
Rainfall tercile	1	3	6	5	9	9	1	7	9	3	6	3	1	6	8	4	7	1
	2	7	6	9	5	5	2	4	3	9	10	5	2	8	3	8	6	6
	3	7	6	5	5	3	3	8	6	8	1	8	3	3	7	8	5	10
	Not significant						Significant at 2·5 per cent level						Not significant					

The significance of the associations according to the chi-square test is indicated where appropriate. Tercile 1 is low rainfall; quintile 1 is much below average temperature.

In the summer months (June, July and August) the inverse association shown in Table I is highly significant. The direct association in the winter months is statistically significant in December and February but not in January, although in that month there is still evidence of a direct association. Except for October the autumn and spring months show no statistically significant relationships, although there is evidently a tendency for May and September to be like summer months (i.e. weak inverse association) and for November to be like the winter months (i.e. weak direct association). In March and April there is, apparently, no association at all between rainfall and temperature on the monthly time-scale. October is peculiar because there is a tendency for dry months to be colder, whereas average rainfall months tend to be warmer than normal; wet months have no strong preference in terms of temperature.

Non-synchronous associations. To show the non-synchronous or lag associations 3×5 contingency tables were prepared, relating monthly rainfall (temperature) with temperature (rainfall) of subsequent months, up to lags of three months. Chi-square tests indicated that there are four statistically significant lag relationships, namely: the associations between

December rainfall and January and February temperature, between August rainfall and September temperature and between June temperature and August rainfall. The first three associations are shown in Table II.

TABLE II—NON-SYNCHRONOUS ASSOCIATIONS BETWEEN ENGLAND AND WALES MONTHLY RAINFALL (TERCILES) AND CENTRAL ENGLAND MONTHLY MEAN TEMPERATURES (QUINTILES) FOR THE 90-YEAR PERIOD DECEMBER 1873 TO NOVEMBER 1963

December rainfall (terciles)	January temperature (quintiles)				
	1	2	3	4	5
1	11	5	6	1	6
2	6	8	3	9	5
3	2	5	9	7	7

Significant at 5 per cent level

December rainfall (terciles)	February temperature (quintiles)				
	1	2	3	4	5
1	5	13	6	1	4
2	8	3	9	6	5
3	5	3	3	9	10

Significant at 1 per cent level

August rainfall (terciles)	September temperature (quintiles)				
	1	2	3	4	5
1	3	1	9	7	8
2	5	6	6	5	8
3	9	11	4	7	1

Significant at 2·5 per cent level

Table II shows that there are direct associations between December rainfall and January temperature and between December rainfall and February temperature, whereas August rainfall has an inverse association with September temperature. The differences between the frequency distributions in the rows relating to the dry and wet months are pronounced. Particularly noteworthy are the contrasts between the frequencies of mild (i.e. quintiles 4 and 5) Februarys and cool (i.e. quintiles 1 and 2) Septembers after dry and wet Decembers and dry and wet Augusts respectively.

In view of the associations between December rainfall and January and February temperature it seemed likely that December rainfall would be a useful predictor of the mean temperature of January plus February. The association in this case is shown in Table III.

TABLE III—RELATIONSHIP BETWEEN ENGLAND AND WALES RAINFALL (TERCILES) IN DECEMBER AND CENTRAL ENGLAND MEAN TEMPERATURE (QUINTILES) OF THE TWO-MONTH PERIOD JANUARY AND FEBRUARY

December rainfall (terciles)	January plus February mean temperature (quintiles)				
	1	2	3	4	5
1	8	8	7	3	3
2	7	5	8	6	6
3	3	5	4	8	9

The two-month (January to February) anomalies from the average temperature of the preceding 25 similar periods were classified into quintiles. The boundaries for quintiles 5/4, 4/3, 3/2, 2/1 are the temperature anomalies greater than or equal to + 1·2 degC, + 0·6 degC, − 0·2 degC and − 1·1 degC respectively. For example, the quintile is 4 when the two-month temperature anomaly is greater than or equal to + 0·6 degC and less than + 1·2 degC. The most recent 25-year (i.e. 1943–1967) mean temperature for the January to February period is + 3·6°C.

The association shown in Table III is not statistically significant, although there is clearly a tendency for dry Decembers to be followed by cold weather and for wet Decembers to be followed by mild weather in the remainder of the winter.

The only statistically significant lag relationship between temperature and subsequent rainfall is shown in Table IV.

TABLE IV—RELATIONSHIP BETWEEN CENTRAL ENGLAND MONTHLY MEAN TEMPERATURE (QUINTILES) IN JUNE, AND ENGLAND AND WALES RAINFALL (TERCILES) IN AUGUST FOR THE 90-YEAR PERIOD DECEMBER 1873 TO NOVEMBER 1963

June temperature (quintiles)	August rainfall (terciles) 1	2	3
1	2	9	8
2	3	10	5
3	9	6	2
4	5	3	10
5	9	2	7

Significant at 1 per cent level

The association shown in Table IV is not simple. Despite the general statistical significance as judged by the chi-square value, there is a suggestion of a random element in the table. However, it is evident that any predictive value derives from rows 1 and 3; these suggest that quintile 1 Junes tend to be followed by tercile 2 or tercile 3 rainfall in August, and that quintile 3 Junes are usually followed by tercile 1 or tercile 2 rainfall in August.

The other month-to-month associations, as indicated by the 3×5 contingency tables, are not statistically significant at the 5 per cent level. However, some of the rows of the contingency tables suggest certain tendencies. These are evident in the frequencies of the quintiles of temperature (in the order 1, 2, 3, 4 and 5) or terciles of rainfall (in the order 1, 2 and 3) in brackets in the abreviated notes given below.

(i)	Wet February	→	cold May	(9, 7, 7, 5, 2)
(ii)	Wet March	→	average to warm May	(4, 4, 8, 8, 9)
(iii)	Wet April	→	average to warm June	(4, 4, 8, 8, 9)
(iv)	Wet July	→	cold October	(9, 9, 6, 5, 3)
(v)	Dry September	→	warm December	(3, 6, 6, 9, 8)
(vi)	Wet September	→	cold December	(9, 5, 5, 4, 3)
(vii)	Wet October	→	average to warm Nov.	(3, 5, 7, 10, 6)
(viii)	Wet October	→	average to cold Dec.	(6, 9, 8, 4, 4)
(ix)	Wet October	→	cold January	(10, 8, 3, 7, 3)
(x)	Dry November	→	average to warm Feb.	(1, 5, 6, 6, 8)
(xi)	Very cold (T_1) January	→	wet March	(4, 5, 10)
(xii)	Cold (T_1 or T_2) March	→	average to wet May	(8, 11, 16)
(xiii)	Warm (T_4 or T_5) March	→	dry to average May	(17, 14, 6)
(xiv)	Very cold (T_1) April	→	wet July	(2, 6, 11)
(xv)	Very cold (T_1) June	→	average to wet August	(2, 9, 8)
(xvi)	Very warm (T_5) July	→	dry September	(10, 6, 2)
(xvii)	Rather warm (T_4) August (but no significant bias following T_3 or T_5 Augusts)	→	wet November	(1, 6, 10)
(xviii)	Very cold (T_1) October	→	dry January	(10, 5, 4)

The suggested trends in items (i) to (xviii) are not strong enough for statistical significance, nor for purposes of prediction in their own right, but they may be useful as empirical background in conjunction with other methods of prediction. The associations given in Table II, perhaps also in Tables III and IV, probably have some predictive value. Certainly, several of the trends and associations suggest that investigations into their synoptic significance might be profitable.

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SOME USES OF PROFILES AND CHARTS OF TOTAL ENERGY CONTENT

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Summary. Vertical profiles of total energy content (Q) are described and it is suggested that Q profiles could usefully supplement the normal tephigram analysis. In particular, Q profiles indicate the levels at which significant ascent has taken place. It is also suggested that charts showing surfaces of constant total energy content have numerous advantages over normal isobaric or contour charts and that they could usefully be constructed to show the airflow in synoptic systems.

Introduction. The analysis of the distribution of the total energy content of the atmosphere, both in the horizontal and vertical planes, acts as a useful guide to the dynamic processes taking place in the atmosphere. The drawing of vertical profiles of total energy content is relatively easy and they yield more information than the conventional tephigram about the dynamic processes taking place in the atmosphere. In this paper the distribution of total energy content is considered from a theoretical viewpoint, examples of distributions in the vertical and in the horizontal are then discussed.

Total energy content. The total energy content of one gram of moist air may be expressed by the following equation :

$$Q = AV^2/2 + Bgz + c_pT + Lq$$

where Q is the total energy content in calories per gramme (cal/g),
V is the wind speed in metres per second (m/s),
g is the acceleration due to gravity (m/s^2),
z is the height above mean sea level in metres,
c_p is the specific heat of air at constant pressure in calories per gramme per degree Celsius (cal/g per degC),
T is the temperature in degrees Kelvin (°K),
L is the latent heat of condensation of water vapour in calories per gramme,
q is the specific humidity in grammes of water vapour per gramme of wet air,
A and B are conversion constants appropriate to the units employed, so that the kinetic energy and potential energy terms are expressed in calories per gramme.

If the vertical motion of the parcel of air is frictionless and adiabatic and if it is assumed that there is no mixing with the surrounding atmosphere, there is a direct conversion between the potential energy (gz) and the sensible heat content (c_pT). It is, therefore, convenient to consider these two quantities together under the heading of total potential energy (TPE).[1] The TPE is, typically, 100 to 1000 times greater than the kinetic energy ($V^2/2$) of the atmosphere. In a powerful jet stream the kinetic energy content will be equivalent to 0·6 to 0·9 cal/g, but the TPE at jet stream level may be between 75 and 80 cal/g. Normally the kinetic energy content is about equal to the probable error in estimating TPE and may, therefore, be neglected in estimations of the total energy content (Q). The TPE content is normally about 10 times greater than the latent heat content (Lq): in a very warm, moist atmosphere the latent heat content may be between 10 and 12 cal/g while the TPE content will be about 70 cal/g.

If condensation is taking place in a rising air parcel, there is conversion of latent heat into TPE. If it is assumed that there is no mixing with the surrounding atmosphere and energy losses due to radiation and the fall-out of condensed water are ignored, the energy content of the parcel will remain

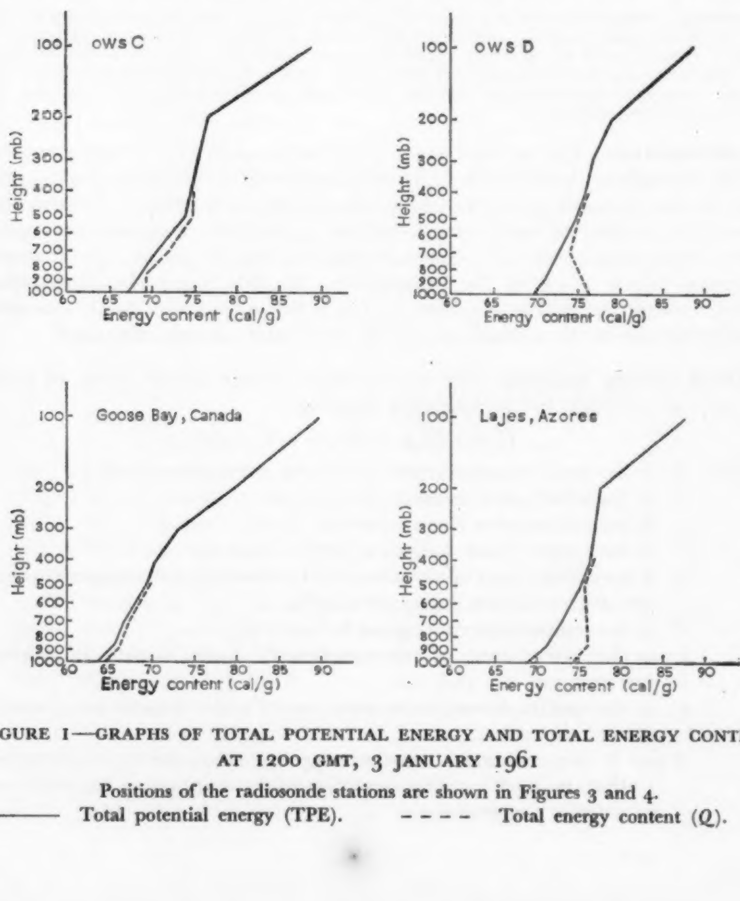

FIGURE 1—GRAPHS OF TOTAL POTENTIAL ENERGY AND TOTAL ENERGY CONTENT AT 1200 GMT, 3 JANUARY 1961

Positions of the radiosonde stations are shown in Figures 3 and 4.

——— Total potential energy (TPE). - - - - Total energy content (Q).

constant during ascent. The graph of Q for such a parcel will be a vertical, straight line showing constant energy on the diagrams contained in Figure 1. The amount of temperature fall attributable mainly to radiation cooling in the atmosphere depends on several factors, but falls of between 1 and 2 degC per day are probably normal. This is equal to a cooling rate of between 0·25 and 0·5 cal/g per day. Clearly, air subsiding very rapidly under conditions of no mixing will maintain an approximately constant Q content and will produce in Figure 1 a graph of Q parallel to the vertical line obtained during ascent. If the air is subsiding slowly, as in an anticyclone, it may take 15 to 20 days to sink from the 300 mb level to the 700 mb level. Under these conditions the air may have cooled gradually during the descent by 5 to 10 cal/g. Profiles of Q through a slowly sinking air mass will, therefore, show a decrease in Q values from the top to the bottom. If no energy is supplied to the atmosphere by the earth's surface and if descent takes place almost to the surface, there will be a minimum in the value of Q at the surface. In anticyclones there is normally a low-level inversion and below the inversion active convection may take place. If the anticyclone is over a warm surface, energy can be transported upward by convection and the layer containing the minimum Q values will be lifted from the surface into the lower atmosphere.

Vertical energy profiles. Vertical profiles of total energy content (Q) act as a useful guide to the broad dynamic processes taking place in the atmosphere. In particular, Q profiles indicate the presence of large-scale ascent; this is illustrated by means of the eight sample profiles contained in Figures 1 and 2.

The profiles were constructed in the following manner. The TPE contents, shown by full lines in Figures 1 and 2, were computed from the published radiosonde data for each of the standard levels. The latent heat contents were also computed for each of the standard levels and were then added to the TPE to give the total energy content, Q, shown by broken lines in Figures 1 and 2. Humidity readings normally ceased above about 400 mb because of the failure of the humidity element in the radiosonde. In temperate latitudes the air above 400 mb is normally very cold and specific humidities are low, therefore the latent heat component of Q is normally small. Above 400 mb the TPE may be taken as a good approximation to Q.

The vertical distribution of Q values has already been described, for tropical areas, by Malkus and Riehl.[2] The Q profiles for Ocean Weather Station (OWS) D on 3 January, 1961 (Figure 1), and OWS E on 4 January, 1961 (Figure 2), were similar to those found in the tropics by Malkus and Riehl. Figures 3 and 4 indicate the synoptic situations associated with the sample Q profiles. The typical tropical Q profile has a relatively high Q content at the surface, above this there is a decrease until a level of minimum Q value is reached somewhere near 850 mb or 700 mb. Above this level the Q content increases slowly until the tropopause is reached, it then increases rapidly in the stratosphere. In the tropics this type of profile is normally associated with undisturbed anticyclonic weather. Above the Q minimum, air has been gradually sinking from high levels and cooling by radiation to space during its descent. At the surface, energy is transferred to the atmosphere in the form of sensible heat and also in the form of latent heat

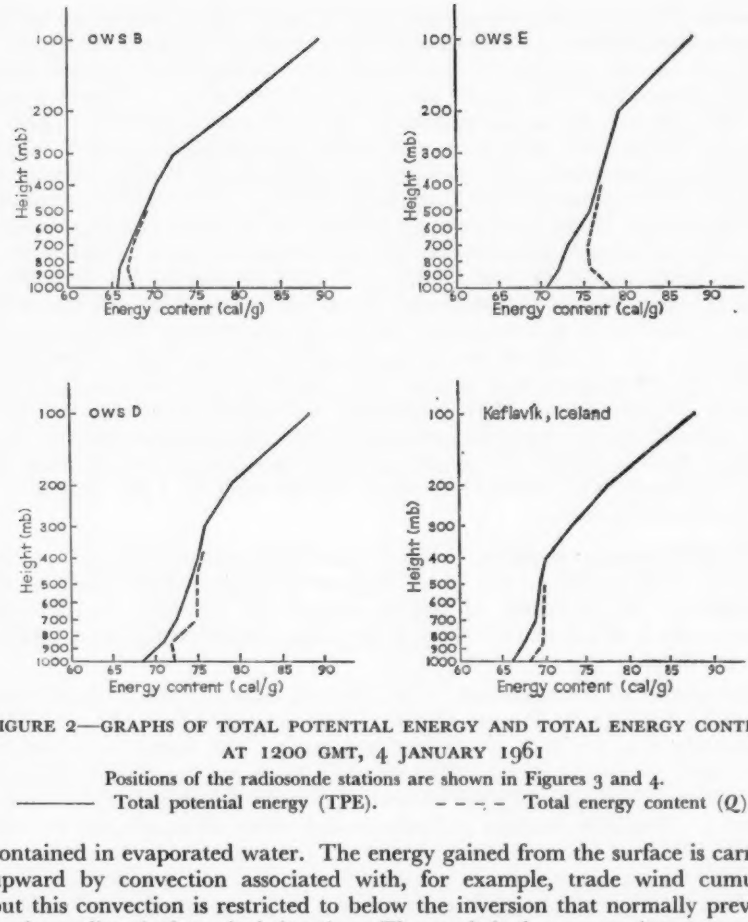

FIGURE 2—GRAPHS OF TOTAL POTENTIAL ENERGY AND TOTAL ENERGY CONTENT AT 1200 GMT, 4 JANUARY 1961

Positions of the radiosonde stations are shown in Figures 3 and 4.

——— Total potential energy (TPE). - - - - Total energy content (Q).

contained in evaporated water. The energy gained from the surface is carried upward by convection associated with, for example, trade wind cumulus but this convection is restricted to below the inversion that normally prevails in the undisturbed tropical situation. The result is that energy is transported, from above and below, towards the minimum of Q, but there is a continual loss of energy to space by radiation, thus the minimum in Q is maintained. On 4 January, ows E was near a subtropical anticyclone and therefore the Q profile may be taken as typical of this type of synoptic system. On 3 January, ows D was in a stable warm sector.

The Q profile for the radiosonde station at Goose Bay on 3 January (Figures 1 and 3) is typical of the Arctic. There was a minimum in Q at ground level and a low tropopause, above which the Q values increased rapidly. The atmosphere was cold and specific humidity was low, therefore the latent heat component of Q was small. The lower atmosphere was losing energy to space by radiation; the ground surface had lost energy by the same means and this resulted in the ground level minimum of Q. The Arctic stratosphere was relatively warm and this is illustrated by the rapid increase of Q with height. On 4 January, ows B (Figure 2) was located in a cold northerly

FIGURE 3—SYNOPTIC SITUATION AT 1200 GMT ON 3 JANUARY 1961
The positions of the radiosonde stations in Figures 1 and 2 are shown.

FIGURE 4—SYNOPTIC SITUATION AT 1200 GMT ON 4 JANUARY 1961
The positions of the radiosonde stations in Figures 1 and 2 are shown.

airstream on the western flank of a depression (Figure 4). This airstream had been over Goose Bay on 3 January, thus the Q profile is typical of cold Arctic air flowing over a relatively warm sea. Compared with the Goose Bay profile, the Q profile at OWS B shows a relatively large latent heat content near the surface, because of evaporation from the relatively warm sea into the cold air. The evaporation was enough to lift the minimum value of Q from the surface up to about 900 mb.

On 3 January, OWS C (Figure 1) was on the western side of a ridge of high pressure with a depression approaching rapidly from the west and a warm frontal surface aloft (Figure 3). The profile of Q showed a two-tier structure; Q was constant from sea level to about 850 mb and then increased until about 500 mb, after which it was constant, or only increased slightly, until the tropopause was reached. The regions of nearly constant Q indicate that ascent was taking place between sea level and about 850 mb, and between 500 mb and about 400 mb in the warm air above the front. At the time of the radiosonde ascent, OWS C reported 8/8 of stratocumulus at 2000 ft and so the upper clouds were obscured. Precipitation was in sight at 1200 GMT and the station reported continuous slight rain at 1800 GMT. The manner in which a frontal surface influences the profile of Q is shown even more clearly by the report from OWS D on 4 January (Figures 2 and 4) when a surface warm front existed about 200 miles to the south of the station. The Q profile showed a marked two-tier structure with evidence of ascent between about 700 mb and 500 mb. The warm front was not particularly active near OWS D but it was active to the west where it caused widespread rain.

A frontal trough lay just to the south of Lagens (Lajes) on 3 January (Figures 1 and 3). The influence of this trough was clearly visible on the profile of Q from Lajes. The Q content was nearly constant between 850 mb and 500 mb, indicating ascent between these two levels. Even above 500 mb the Q content increased only slowly until the tropopause was reached. This was a markedly different profile from that found in the undisturbed tropical anticyclone. The Keflavík profile for 4 January (Figures 2 and 4) was a colder version of the Lajes profile. A depression was centred to the south of Iceland; the Q profile between 850 mb and 500 mb indicated ascent and showers were reported from the Iceland region.

The Q profiles discussed above are only a small sample of the many possible, but they illustrate clearly some properties of the profiles. The most interesting of these include the indication of the dynamic and thermodynamic processes taking place. The Q profile can indicate whether the atmosphere is gaining or losing energy, particularly in the lower layers. A comparison of the Q profiles for Goose Bay (Figure 1) and OWS E (Figure 2) illustrates this point. It is clear that at Goose Bay the atmosphere is cooling right to the surface but at OWS E it is gaining energy from the surface. More usefully, the Q profiles indicate clearly the levels at which ascent is taking place. The rate of ascent cannot be calculated without additional wind data and, this is considered in the next section; nevertheless, the vertical depth of the layers in which ascent is taking place is clearly indicated.

It is not suggested that Q profiles can replace tephigrams. It is suggested that they can usefully supplement them, particularly in analysing synoptic systems.

Surfaces of constant total energy content. Over periods of a few days, the total energy content (Q) of air particles in the free atmosphere remains approximately constant. It is, therefore, possible to use the Q content as a 'label' on air particles and thereby trace their motions in three dimensions. The most convenient way of doing this is by drawing surfaces of constant Q and constructing streamlines on these surfaces. The height above MSL of the surfaces of constant Q can be shown by contours or, preferably, by isobars. It is thereby possible to produce a chart that shows the approximate instantaneous three-dimensional air motion. The surfaces of constant Q are best referred to by quoting the particular Q content being mapped, for example, the 83-surface or the 83 calorie per gramme surface.

Charts of surfaces with a constant Q value have several advantages over the more normal isobaric charts. In particular, they give a direct and simple picture of the verticle motions and the physical processes at work in the atmosphere. Green, Ludlam and McIlveen[3] have recently advocated the use of charts showing the flow aloft along (isentropic) surfaces of constant potential temperature. The diagrams produced in this paper are equivalent to charts showing the flow aloft along surfaces of constant wet-bulb potential temperature which, because they are not influenced by rainfall, can be drawn through areas of precipitation: this is not so with surfaces of constant potential temperature. The uses of this particular type of chart are illustrated for two contrasting synoptic situations over India; one is a tropical storm, the other is typical of the north-east monsoon season.

A technical difficulty in the construction of charts to show surfaces of constant Q is that the humidity element of most radiosondes fails above about 400 mb. In the tropical storm over India (July 1964) the humidity values were high, therefore humidity values had to be extrapolated for levels above 400 mb. In the lower layers relative humidity values were near 100 per cent and, because air was rising in the storm, it was assumed that relative humidity values in the upper parts of the storm were also near 100 per cent and Q values were calculated for levels above 400 mb on this assumption. The upper atmosphere over India during the north-east monsoon synoptic situation (Figure 8) was very dry; therefore, for levels above 400 mb, Q was considered equal to the TPE.

During early July 1964, a tropical storm developed in the Bay of Bengal and moved westwards into northern India. At 0000 GMT on 4 July 1964, the storm was centred to the north of Calcutta while a minor disturbance existed over West Pakistan. The pattern of airflow in the tropical storm on 4 July is well illustrated by the flow along the surface with a constant Q value of 83 cal/g (Figure 5). To construct this diagram the heights, in millibars, of the 83-surface were computed for each of the available radiosonde ascents. At some distance from the storm centre each ascent passed through the 83-surface twice, once near the ground and once at about 200 mb. Nearer to the storm centre all the Q values were greater than 83 cal/g: the shape of the 83-surface is, therefore, of the nature of a hyperboloid. Winds at the levels of the 83-surface were also plotted on the diagram and streamlines were constructed. The distance between the streamlines is inversely proportional to the wind speed.

The picture that emerges from Figure 5 is one of air flowing into the storm at low levels, rising rapidly near the storm centre and flowing out at high

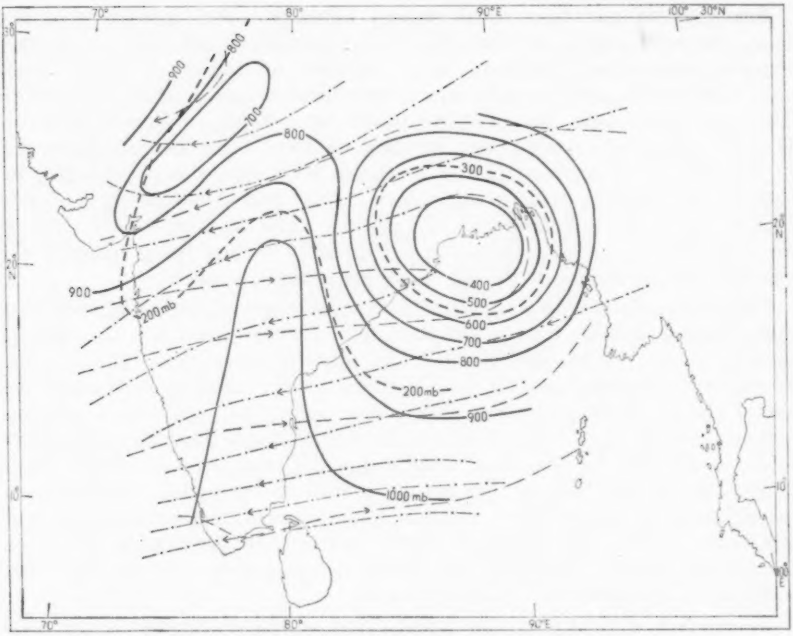

FIGURE 5—CONTOURS AND STREAMLINES OF THE 83 CALORIE PER GRAMME SURFACE AT 0000 GMT ON 4 JULY 1964

——— Isobaric heights of the lower surface
- - - - Isobaric heights of the upper surface
— — — Flow along lower surface (direction shown by arrow)
—·—·— Flow along upper surface (direction shown by arrow)

levels. The picture of the airflow thus presented is partly schematic because the observational data were too sparse to allow a detailed flow pattern to be constructed. The main ascent along the 83-surface was over east-central India where the streamlines rose from 900 mb to 400 mb in a relatively short distance. The rainfall over much of east-central India between 1200 GMT on 3 July and 0300 GMT on 4 July averaged about 60 mm (Figure 6): this implies an average rainfall rate of about 4 mm/h. If the atmosphere over east-central India is assumed to be almost saturated and has a surface dew-point of about 25°C then an ascent rate of about 6 to 15 cm/s in the lower atmosphere would be required to produce a rainfall rate of 4 mm/h. The calculated vertical component of the airflow at the 83-surface over east-central India was about 15 cm/s. The values are close enough to indicate that the rainfall over east-central India was associated with the airflow along the marked upward curve of the 83-surface. On 4 July there was a minor disturbance over West Pakistan. Figure 5 shows that there was no active ascent into this disturbance and that subsidence might have been occurring: rainfall amounts from the system were low.

The flow along the 83-surface does not explain the rainfall along the west coast of India in Figure 6 but the 81-surface (Figure 7) shows clearly that air was rising from the Arabian Sea over the Western Ghats and then sinking

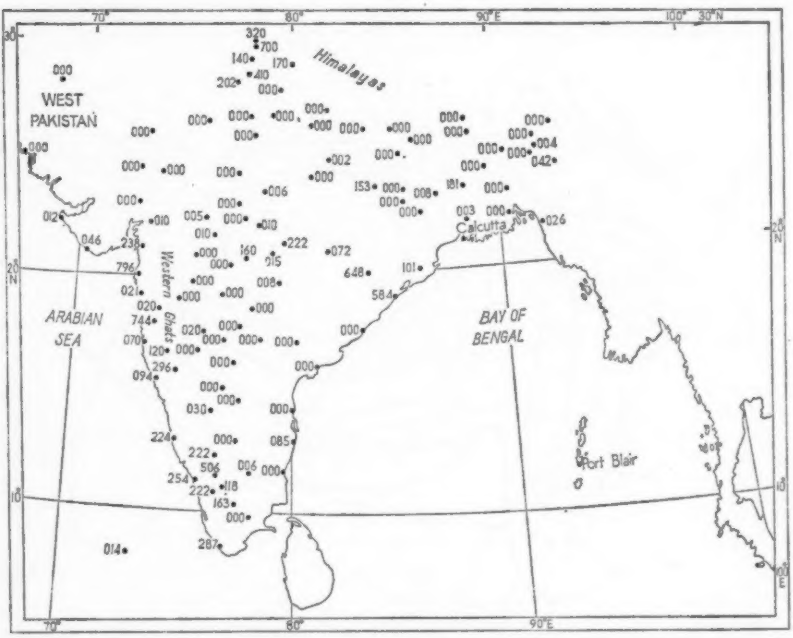

FIGURE 6—RAINFALL DURING THE PERIOD FROM 1200 GMT ON 3 JULY 1964 UNTIL 0300 GMT ON 4 JULY 1964

Rainfall amounts are plotted in tenths of millimetres.

over eastern India. The 81-surface had the same general shape as the 83-surface, but it was farther from the storm centre. The lower level of the 81-surface lay above the lower level of the 83-surface, and the upper level of the 81-surface lay below that of the 83-surface. By the careful choice of constant Q surfaces it is, therefore, possible to study the flow patterns in different layers of the storm. Isobaric charts would show the flow patterns in horizontal plan through the storm. The constant Q layers follow the actual three-dimensional motion in the storm; as the Q values rise so motion nearer to the storm centre is observed.

The 80-surface for a typical synoptic situation during the north-east monsoon season is shown in Figure 8. At 700 mb a trough existed over the Bay of Bengal and a ridge lay over India, with some minor disturbances over northern India. At 300 mb a powerful jet stream existed over northern India; this is clearly shown by the close spacing of the streamlines in Figure 8. The upper and lower levels of the 80-surface appeared to be connected in the 700 mb trough near Port Blair. There was no significant ascent in the region of Port Blair because the flow along the lower level of the 80-surface was slight. This lack of significant ascent is confirmed by the weather, which was fine and dry over most of southern Asia including Port Blair.

Conclusion. The analysis of total energy content (Q) has been considered mainly as a means of recognizing dynamic processes taking place in the

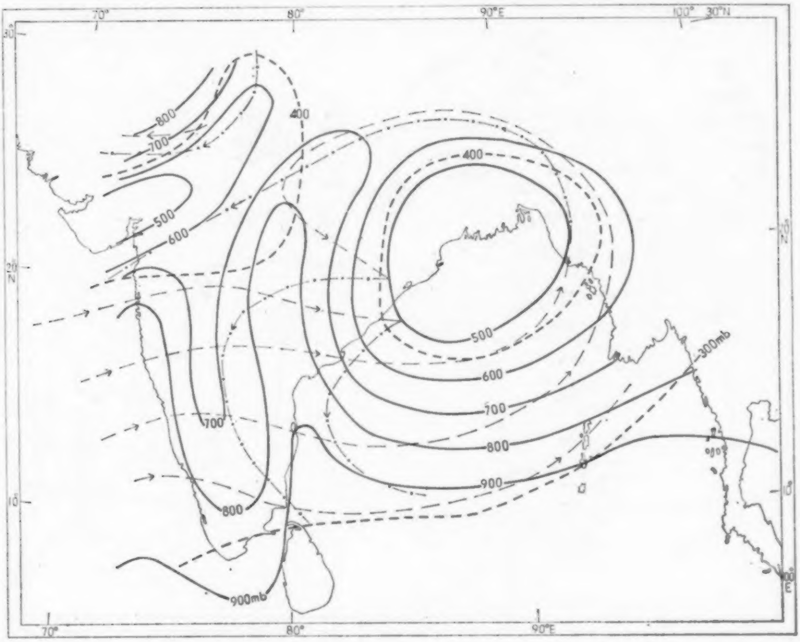

FIGURE 7—CONTOURS AND STREAMLINES OF THE 81 CALORIE PER GRAMME SURFACE AT 0000 GMT ON 4 JULY 1964

Legend as in Figure 5.

atmosphere. The mapping of Q content can also give further insight into the energy exchange processes taking place in the atmosphere. The normal Q profile shows a minimum value somewhere in the middle troposphere with increasing values in the upper troposphere and the stratosphere. In the stratosphere, temperatures are almost constant with height because of a near balance between incoming and outgoing radiation, therefore Q will increase with height. In this context it should be remembered that Q values are per gramme of air and at high levels one gramme of air occupies a very large volume (densities are low), hence the high Q values in the stratosphere are not inconsistent, and the stratosphere cannot act as a significant energy source for the upper troposphere. The upper troposphere is normally losing heat energy to space, so the Q content should fall steadily and this would be reflected by a fall in temperature and a decrease in the height of the air particles. Various workers[2] have suggested that the energy lost by radiation to space from the upper troposphere is replaced from below. This replacement cannot take place except by large masses of air rising quickly and carrying their associated Q contents aloft and this cannot occur on a large scale, except in the rain-producing synoptic systems. The charts of constant Q surfaces in Figures 5 and 7 indicate that the storm was transporting air with a high Q content from near the sea surface to high in the troposphere. Near the sea surface this high Q content was partly in the form of latent heat. In the

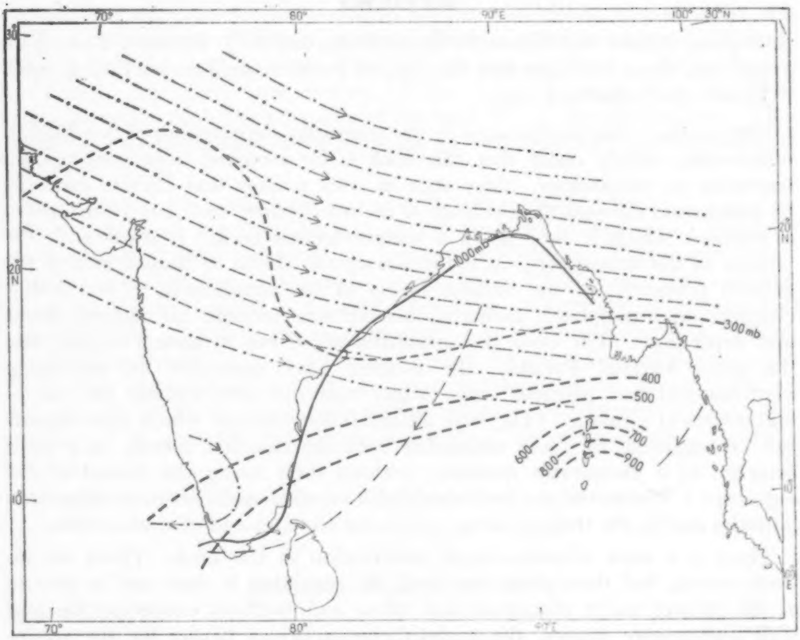

FIGURE 8—CONTOURS AND STREAMLINES OF THE 80 CALORIE PER GRAMME SURFACE AT 0000 GMT ON 7 FEBRUARY 1964

Legend as in Figure 5.

storm, condensation and rainfall occurred and the latent heat was converted into TPE. In figures 5 and 7 the transfer of high Q values from low to high altitudes did not occur on a significant scale except in the tropical storm. There were high orographic rainfalls over the Western Ghats but there was no evidence that the latent heat so released was transferred to the upper troposphere at the Western Ghats.

It is suggested that a clearer picture of the flow in the atmosphere could be gained by constructing charts to show streamlines on surfaces of constant Q. The amount of work required to construct these charts is greater than that required for the construction of isobaric or contour charts, but they yield more information than isobaric charts and they could be very useful in tropical areas.

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REVIEWS

Atmosphere, Weather and Climate, by R. G. Barry and R. J. Chorley. 8 in × 5 in, pp. 319, *illus.*, Methuen and Co. Ltd, 11 Fetter Lane, London E.C. 4, 1968. Price: 45*s* (paperback 25*s*).

The authors, who are lecturers in the geography departments of two English universities, rightly claim that this book is far removed from conventional textbooks on climatology. They state in their preface that climate can only be understood through the workings of the atmosphere, and they have written a textbook which is very much a meteorologist's book. It starts with the physics of the atmosphere, its composition, the effects of insolation and the general properties of the various layers of the atmosphere. Then follow chapters on atmospheric moisture, atmospheric motion, air masses, fronts and depressions. The book is non-mathematical but in these chapters, like the great Michael Faraday, the authors have succeeded in expressing mathematical and physical ideas clearly and concisely without the use of mathematical symbols. (The odd differential coefficient which does appear can be regarded, by those unfamiliar with the calculus, merely as a label attached to a measurable quantity, without their losing the thread of the argument.) The rest of the book deals with weather and climate in temperate latitudes and in the tropics, urban and forest climates and climatic trends.

There is a mass of well-ordered information in this book. There are no waste words, but throughout the book the reasoning is clear and as precise as the subject under discussion will allow and, without cluttering the text with unnecessary figures, the authors give sufficient figures for the reader always to be aware of the order of quantities involved. The book is remarkably up to date and the authors are completely justified in their claim to have incorporated much that has not, hitherto, found its way out of scientific papers and into an elementary textbook.

The print is easy to read and the book is liberally illustrated with clear diagrams.

To summarize, this is a very good elementary textbook which deserves to be widely read by students in geography departments of universities and sixth forms — the public for whom it is intended. It would also provide useful background reading for any Scientific Assistant in the Meteorological Office who aspires to become an Assistant Experimental Officer.

S. E. VIRGO

Magyarország Éghajlati Atlasza, II, Kötet, Adattár. Klima-Atlas von Ungarn, Band II, Tabellen. 11½ in × 8½ in, pp. 263 + 1 looseleaf map. Akadémiai Kiadó, (Publishing House of the Hungarian Academy of Sciences), Budapest, V. Alkotmány U. 21. (Price and date of publication not stated.)

The first volume of the Klima-Atlas von Ungarn, which consisted entirely of maps, was published as long ago as 1960. Now, the publication of the second volume, which consists entirely of tables, fills a gap which has long been apparent in any study of the climate of Hungary. For the first time averages, extremes or frequencies of meteorological elements are conveniently collected in one volume. Part I deals with precipitation and Part II with other climatological elements. Monthly values are given in the tables,

whereas the maps in the first volume are for mid-season months only. In addition to statistics relating to a comprehensive selection of usual elements there are tables dealing with radiation, evapotranspiration, water excess and deficit, and earth temperature. There is also a table of averages of temperature for each calendar day of the year for six selected stations. The period used for the statistics is mainly 1901–50 but there are some unavoidable exceptions to this.

An appendix contains long series of monthly means, year by year, of temperature, and monthly totals, year by year, of precipitation, duration of sunshine and total radiation on a horizontal surface. Explanations and headings of tables are in German as well as in Hungarian. Two editing errors have been noticed — the table headings in German on the second pages of Tables 58 and 59 do not correspond with those in Hungarian. There are useful analytical indexes of stations — one for each part of the volume. These show the position, altitude and identification number for each station and also the tables in which each station appears. A key map showing the position of all the 786 stations is included. This map is loose, for easy reference.

Altogether, this is a useful and well-planned work of reference.

F. V. REED

RECENT PUBLICATIONS

Polar Meteorology.

More complete knowledge of the meteorology of the Arctic and the Antarctic is basic for man's understanding of global weather variations. It is against this background of the need for detailed and comprehensive information about polar meteorology, which is so important to the meteorologist's attack on the problems involved in long-range weather prediction, that the World Meteorological Organization (WMO) has published a collection of research studies on the meteorology of polar regions.*

The poles, like the tropics, are fundamental to the global movement of air and water masses — the processes that create weather systems. While the physical characteristics of the two polar regions are different (one is a sea area and the other is a continent) and their climatic patterns have certain dissimilarities, there is, nevertheless, much in common in the research problems that face scientific workers in both regions.

With these common problems in view, in September 1966 a symposium was held at the WMO Secretariat in Geneva which, for the first time, made it possible to bring together the results of research in both areas. This international exchange of polar meteorological knowledge, with its opportunities for comparisons between Arctic and Antarctic meteorology, was sponsored by the WMO, the International Commission on Polar Meteorology (ICPM) and the Scientific Committee on Antarctic Research (SCAR).

The scientific papers presented at this symposium have now been published in the volume under review.

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* *Polar Meteorology,* WMO Technical Note No. 87. Proceedings of the WMO/SCAR/ICPM Symposium on Polar Meteorology, Geneva, 5–9 September 1966. Available from the World Meteorological Organization Secretariat, Geneva. Price: Sw. F. 78.

Many of the studies in this collection are concerned with the same phenomena that the meteorologist observes in other parts of the world: wind circulation at various heights, water vapour and ozone in the atmosphere, solar radiation and so on. All these are important data and they must be accumulated over long periods if accurate scientific investigations are to be made of polar weather conditions and of their relationship to climate in other parts of the world.

However, a great deal of the research material published in 'Polar Meteorology' is concerned with phenomena which occur only in the polar environment; studies of the effects of snow and ice on the incident solar radiation; observations of the occurrence of sea ice, pack ice and bergs and the way this is linked with long-term changes in weather patterns in other regions such as South America, South Africa and Australia. Also included are investigations of the so-called 'heat balance' of the Antarctic — in other words, the heat exchange that takes place between surface snow and ice and their surroundings. This is related to snow accumulation and, in turn, to the temperature variations of the layers of the atmosphere near the surface of the Antarctic.

This new WMO publication is likely to be a standard reference on the subject of polar meteorology for some time to come. It makes available much of the recent meteorological data gathered in the polar regions and, at the same time, points to the gaps in present scientific knowledge of the weather of these areas and suggests avenues for further research.

The U.S. Standard Atmosphere Supplements, 1966.

The United States Committee on Extension to the Standard Atmosphere (COESA) arranged for the preparation of the U.S. Standard Atmosphere Supplements, 1966,* in response to a need for atmospheric models depicting conditions other than idealized mid-latitude mean which were represented by the tables of U.S. Standard Atmosphere, 1962. Tables of typical winter and summer conditions for various latitudes extend through the troposphere, stratosphere and mesosphere, to about 80 km. Eight of these are continued to the lower thermosphere where they merge into three different boundary conditions at 120 km; summer, winter and spring/fall. Models related to the wide range of conditions in the thermosphere associated with varying solar activity, geomagnetic activity and zenith angle of the sun extend to 1000 km.

The substance of this publication is two major sets of tables; those for the region below 120 km, keyed to seasonal and latitudinal variations; and those for 120–1000 km, keyed to solar activity, geomagnetic activity and solar angle. These two sets of tables, though separated, have mutual boundary-conditions so that users will be able to select, for any location, season and solar activity, the appropriate continuous profiles of atmospheric properties

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* *U.S. Standard Atmosphere Supplements, 1966.* Sponsors: Environmental Science Services Administration, National Aeronautics and Space Administration, U.S. Air Force. Published in 1967 and available from: Superintendent of Documents, U.S. Government Printing Office, Washington, D.C. 20402. Price: $4.00.

from the surface up to 1000 km. Profiles of atmospheric properties for any orbital or re-entry trajectory can thus be estimated.

In addition, this publication contains information on diurnal variations in density for regions up to 90 km, refined analytic expressions which represent pressure and density profiles of the 1962 Standard and 1966 Supplementary Atmospheres up to 80 km, and a mid-latitude ozone model up to 50 km. Tables providing the altitude variation of geopotential surfaces as a function of latitude are also included, to facilitate application of the atmospheric tables to all locations. For those interested in aircraft pressure altimetry, a set of detailed pressure altitude tables from the surface up to 10 mb is provided.

The general background leading to development of this publication is contained in the Foreword. Technical background is presented in Part 1 — Basis of the Tables. Parts 2 and 3 provide detailed insight on the development of the two major sets of tables and include presentations of pertinent supporting data. Part 4 contains the additional material on analytic approximations, ozone and geopotential–geometric altitude relations. Parts 5 and 6 are the detailed tables of the atmospheres. Throughout the document, figures and tables have been introduced to permit visual comparisons of the varying conditions presented. Major tables are presented in both English and metric systems for regions up to 120 km. Above 120 km, only metric tables are provided.

Meteorological Problems in the Design and Operation of Supersonic Aircraft.

New meteorological problems arising in the design and operation of supersonic aircraft are discussed in a Technical Note* recently issued by the World Meteorological Organization. Its authors point out that with the design of commercial supersonic aircraft going ahead and their introduction planned for the early 1970's these new problems require urgent study.

The Technical Note discusses these problems in relation to the main phases of supersonic flight — the take-off and initial climb, the transonic phase (during which the aircraft accelerates from subsonic or normal jet speed to supersonic cruising speed), the cruise phase, and deceleration and landing. Since the performance of a jet engine is affected to a great extent by the outside temperature — the thrust decreases with increasing temperature — it is important to have reliable data and forecasts of temperature for all phases of the flight. Such forecasts are needed particularly for the transonic phase, during which full engine capacity is required. In certain circumstances it will be economical, to gain time and save fuel, to divert supersonic aircraft from what is known as the 'great circle' route (the shortest route between two points on the globe is an arc of the great circle that passes through the two points). The circumstances under which such route diversions may be advantageous — for example, to avoid strong headwinds or excessively high temperatures — are discussed.

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* *Meteorological Problems in the Design and Operation of Supersonic Aircraft*, by R. F. Jones, R. M. McInturff and S. Teweles. WMO Technical Note No. 89. Available from the World Meteorological Organization Secretariat, Geneva. Price: Sw. F. 9.

A section of this Technical Note concerns the problem of sonic boom and it is shown how its intensity at ground level is influenced by, among other things, various meteorological factors, for instance: the rate of change of temperature and wind speed and direction with increasing altitude — and even, although to a lesser extent, humidity and cloud cover. Turbulence is another factor examined. The importance of the observation and forecasting of meteorological phenomena that lead to turbulence, such as jet streams, mountain waves and cloud formation, is stressed. Devices may have to be used to protect both passengers and crew on supersonic flights from exposure to ozone by keeping its concentration at acceptably low levels. Effective warning systems against cosmic radiation may also be needed.

The Technical Note concludes with an examination of the main deficiencies in man's knowledge of the higher atmosphere in which supersonic aircraft will operate, and of the observational problems which have to be solved if adequate meteorological services to supersonic aircraft are to be provided.

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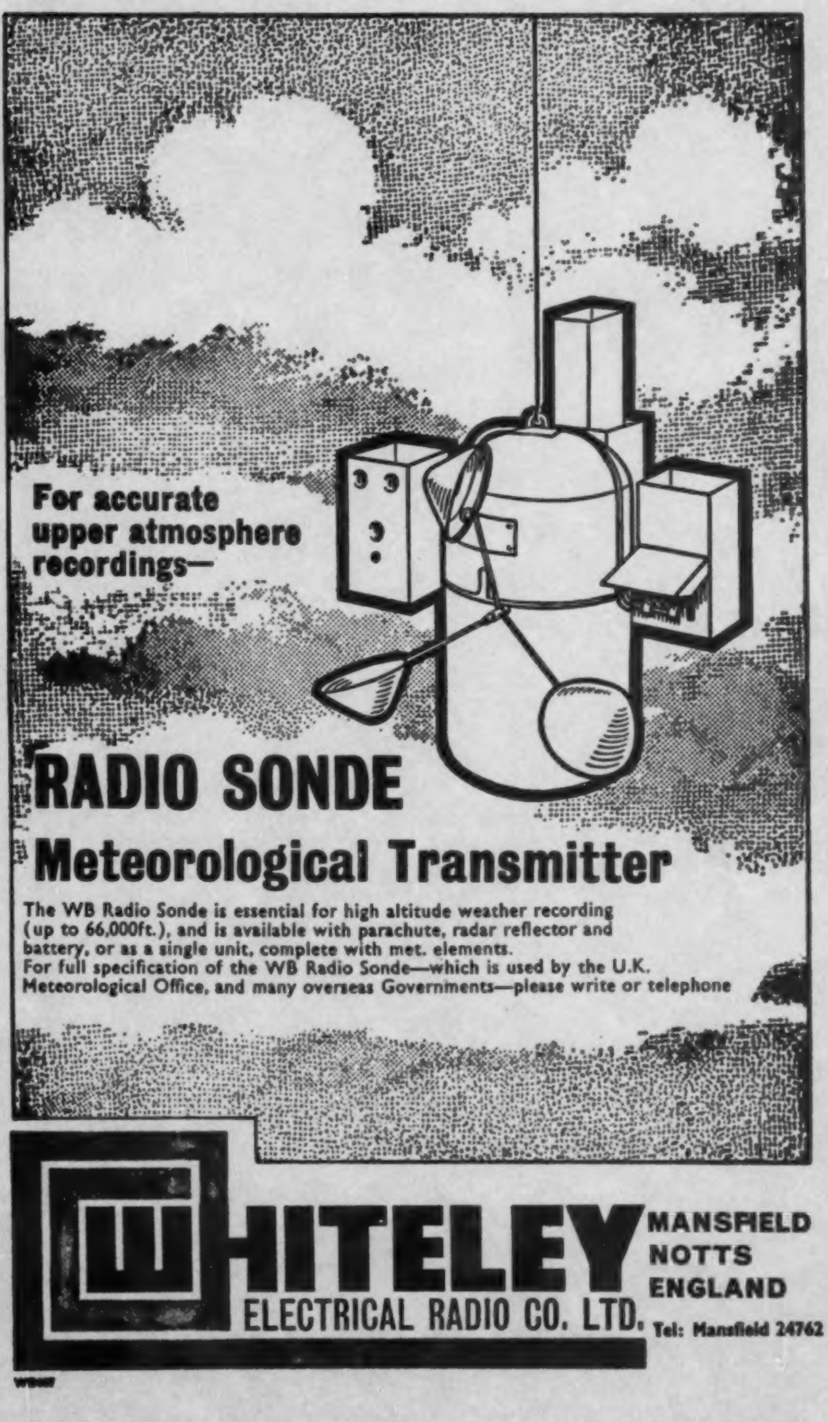
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CONTENTS

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